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COMPARISON OF CYLINDRICAL ELECTROSTATIC PROBE MEASUREMENTS ON ALOUETTE II AND EXPLORER 31 SATELLITES

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ABSTRACT

The Alouette II and Explorer 31 satellites were placed in orbit by a single vehicle and separated. Cylindrical electrostatic probes were employed on both satellites in part to test the effects of the long sounder antennae and large radio frequency power upon direct measurements of the thermal electrons and ions. Comparison of the early data taken when the satellites were separated less than 1000 kilometers along their common orbit suggest that there is no inherent incompatibility between the sounder experiment and direct measurement experiments. The electron temperature (T_e) and concentration (N_e) derived from the two experiments generally agree to better than 10% although unexplained differences of up to 15% in T_e and 40% in N_e have been found on rare occasions.

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INTRODUCTION

Early in the history of the topside sounder program it was recognized that the N_e profiles derived from Alouette I ionograms could not be interpreted unambiguously in terms of the ion and electron temperature and ion composition (Bauer and Blumble, 1964), even with the simplifying assumption of diffusive equilibrium. The field-aligned distributions of electrons are affected by the unknown temperature gradients along the field lines, and the diurnal variations observed in the electron concentration must be associated with ionization fluxes which can produce significant deviations from diffusive equilibrium (Hanson 1964) (Hanson and Patterson, 1963).

To help reduce the ambiguity in interpreting the N_e profiles, the second topside sounder satellite, Alouette II, was accompanied by the Explorer 31 satellite which carried equipment for measuring ion composition, ion temperature, and electron temperature. The two satellites were placed in essentially identical orbits by a single vehicle. The two satellite approach was necessary because of the many difficulties involved in adding the needed direct sampling experiments to the existing Alouette II spacecraft. In addition, the compatibility of these experiments with the sounder experiment was in question, particularly with respect to the effects of the very long antennae and high power sounder pulses. To help resolve these questions of compatibility, the cylindrical probe experiment was placed on both satellites. It is the purpose of this paper to present several comparisons of probe measurements obtained simultaneously on the two satellites and to discuss their implications for future missions which combine both the sounder and direct measurements on a single spacecraft. In another paper in this issue (Donley, et al, 1968), the direct measurements on Explorer 31 are compared with each other and with the sounder measurements of N_e at the satellite altitude.

EXPERIMENTS

In a companion paper Findlay and Brace (1968) have described the cylindrical probe measurement technique and its implementation on Alouette II and Explorer 31. In this paper we discuss only those additional aspects of the experiment and methods of data analysis which bear upon the validity of the intercomparison of data from these spacecraft.

Spin Modulation

One such consideration is the nature of the effects of orientation upon the current characteristics. Two major sources of spin modulation are observed, one related to the velocity vector and the second associated with the geomagnetic field. The most serious of these by far is the velocity wake. This is especially important at low altitudes where the satellite velocity greatly exceeds the ion thermal velocity. Under these conditions, the ion and electron concentrations may be reduced by over an order of magnitude in the wake of the spacecraft. At higher altitudes, where the thermal velocity of the ions often exceeds the satellite velocity, the wake effect becomes negligibly small (less than 10% depression of current in the wake).

The magnetic modulation affects are apparent only in the electron current and take the form of a broad minimum of current as the probe axis passes parallel or antiparallel with the field. This phenomenon becomes detectable at higher altitudes (nominally above 1000 kilometers). Spin modulation in electron temperature is also found on many of the passes which exhibit a strong magnetic modulation. This temperature modulation may reflect an anisotropy in which the temperature parallel to the field differs from that perpendicular to the field.

It is not our purpose to discuss the causes of these spin modulations but merely to acknowledge that their existence places limits upon the precision of comparisons between identical experiments on the different satellites or comparisons of different experiments on the same satellite (see companion paper by Donley et al 1968). The comparison problem is expecially complex for the probes on these two satellites because their orientation in space is different (and unknown in the case of the Alouette-II probes) and the satellite spin axes are aligned differently (Findlay and Brace, 1968).

Method of Data Analysis

A second difficulty encountered in making realistic comparisons between Alouette II and Explorer 31 probe measurements arises from the different data systems employed and thus the different methods of data handling required.

The analysis of Explorer 31 probe data is handled entirely by computer, employing a program which applies the theory to the volt-ampere characteristics. The analysis program for T_e employs a sequence of 30 seconds of data (approximately 24 curves taken at all orientations) and rejects values which are more than 1.5 standard deviations from the mean of the set. The analysis program for N_e also employs a 30 second sequence but applies the orientation data to reject wake curves. Both programs then average the sequence of values to provide T_e and N_e at about one minute intervals throughout the pass.

The Alouette-II probe data analysis is carried out directly from microfilm analog records of the volt-ampere characteristics. Lacking aspect data, we examine each sequence of curves for evidence of wake effects, then scale the temperature and concentration from the curves which are not in the wake. The choice of curve for scaling is also somewhat limited by sounder pulse interference which is often large enough to prevent a determination of T_e when the sounder is operating near or below the plasma frequency. Further discussion of the sounder interference is contained in a companion paper (Findlay and Brace, 1968).

COMPARISONS

Several early passes of the satellites have been selected for comparison. Only data from the first two months after launch are employed since the satellites soon drifted too far apart to assure a high degree of simultaneity. These data are shown in Figures 1 through 6. The time scales are shifted relative to each other to place the measurements on a nearly common geographic scale.

One of these passes, Figure 4, displayed a large change in N_e through the pass; and volt-ampere characteristics recorded at the beginning and end of this pass are compared in Figures 7, 8 and 9. Figure 7 compares Alouette II and Explorer 31 curves at low N_e ($\hat{\approx} 2 \times 10^3$/cc) when both T_e and N_e are derived from the most sensitive detector ($0.02 \mu a$ full scale). The N_e can be resolved to concentrations at least an order of magnitude lower ($\hat{\approx} 10^2$/cc), but resolution of the electron retardation region becomes inadequate for T_e below 1×10^3/cc. This is not an inherent limitation of the technique but rather a limitation imposed by the maximum sensitivity employed in these instruments.

The larger currents encountered at the end of this pass (WNK 550) could be resolved on both the $0.02 \mu a$ and $0.15 \mu a$ current ranges as shown in Figures 8 and 9. At these concentrations T_e would be derived from the $0.02 \mu a$ range and N_e from the $0.15 \mu a$ range.

Both Figures 7 and 9 indicate that the Explorer 31 probe collected slightly more current that the Alouette-II probe, but this does not represent a trend, as can be seen in the various N_e comparisons shown in Figures 1 through 6.

To compare the instantaneous T_e measurements, the volt-ampere characteristics in Figure 8 were plotted on a logarithmic scale with a suitable subtraction of the ion current which is resolved at the left of the characteristics. The result, in Figure 10, shows negligible difference in the slope of the log of I_e, a factor which is inversely proportional to T_e.

Although the agreement in T_e and N_e is usually better than 10%, there are notable exceptions. For example, in Figure 2, the values of N_e in the region of apparent overlap disagree by about 40%. Similarly, in Figure 5, the values of T_e differ by 15% at one point in the pass. It is not generally possible to determine whether these occasional disagreements represent (1) real temporal or spatial differences along the slightly different paths taken by the two satellites, or (2) unexplained experimental errors. In either case, their occurrence is not sufficiently frequent to cast doubt on the ability of either system to resolve the temperature and density of the plasma it encounters.

IMPLICATION FOR OTHER EXPERIMENTS AND LATER SATELLITES

The agreement found between these identical collectors on the two satellites of course does not guarantee that all direct sampling devices will be compatible with sounder systems on all future satellites. At least three potential sources of incompatibility have been identified which may compromise given experiments on future sounder satellites. These are (1) wake effects produced by the large sounder antenna, (2) sounder pulse interference induced at the input of the highly sensitive current detection systems employed, and (3) sounder pulse disturbance of the nearby plasma and the spacecraft's equilibrium potential.

It appears that the wake effects are reasonably well understood and can be avoided by suitable selection of sensor mounting positions, by adequate control of the spacecraft attitude and by rejection of data taken in the wake. The interference from the sounder pulses is much more difficult to avoid, however. The electrometer frequency response required by most experiments is comparable to the pulse repetition rate and the plasma recovery times. Therefore the sounder pulses cannot usually be removed adequately by filtering. Since present trends in sounder design are toward even high repetition rates it appears that a full set of good direct measurements can be assured only with intermittent operation of the sounder. The Alouette II sounder provided this in the form of a 4-second off period between sounder sweeps, and the ISIS-A and ISIS-B spacecraft also have provision for an intermittent mode of sounder operation.

CONCLUSIONS

From the comparisons presented here, as well as others not shown, we have concluded that one can generally expect agreement between measurements by cylindrical probes on separate satellites in identical plasma. Furthermore, when intermittent operation of the sounder and suitable spacecraft altitude control are provided, the accuracy of this and other direct measurements on future satellites will not be degraded by the presence of the sounder antennae and its pulse transmissions.

ACKNOWLEDGMENTS

The design and fabrication of the electronic systems was by Tuck Bin Lee at the University of Michigan. We thank John Sayler and Larry Rudolph for their efforts toward developing the analysis programs employed for the Explorer 31 data.

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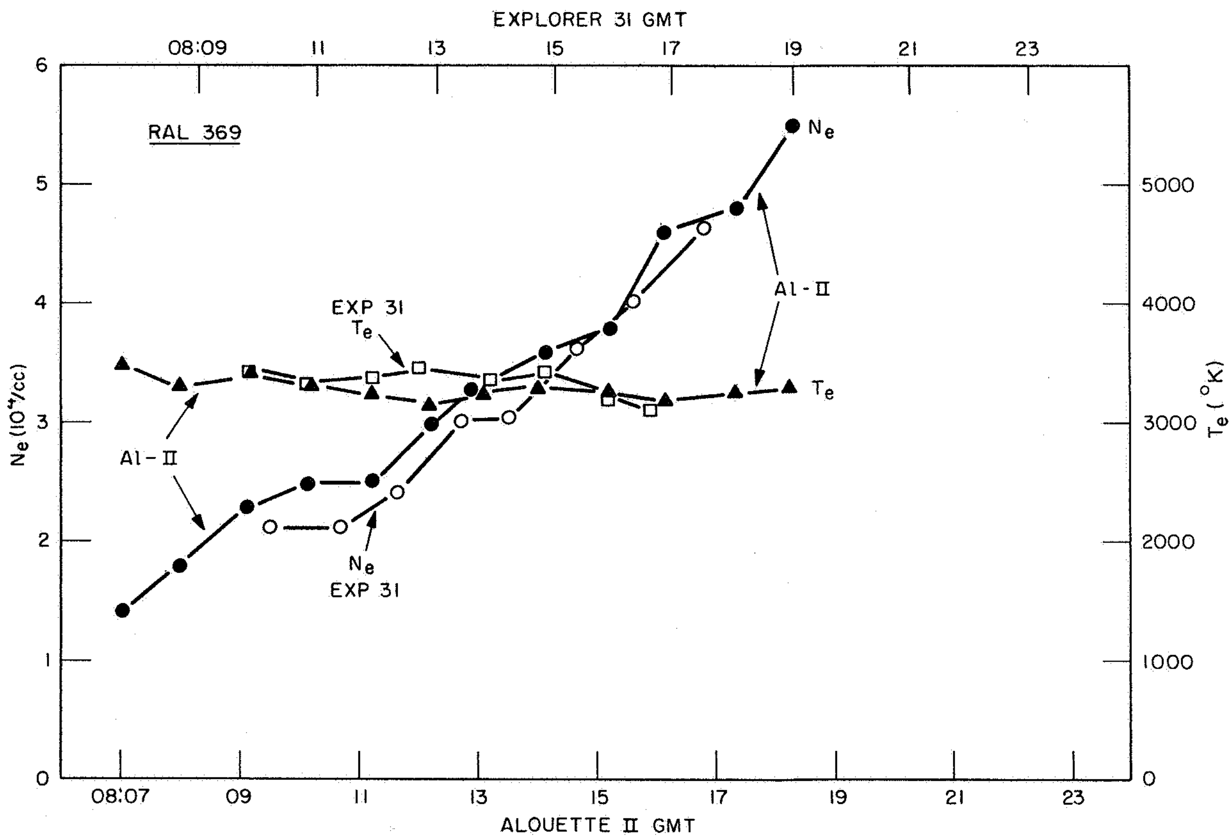

Figure 1—Comparison of Alouette II and Explorer 31 Cylindrical Electrostatic Probe Measurements on a Southbound Pass Over Australia on December 30, 1965 at an Altitude of About 1000 Kilometers and a Local Time of 1800 Hours

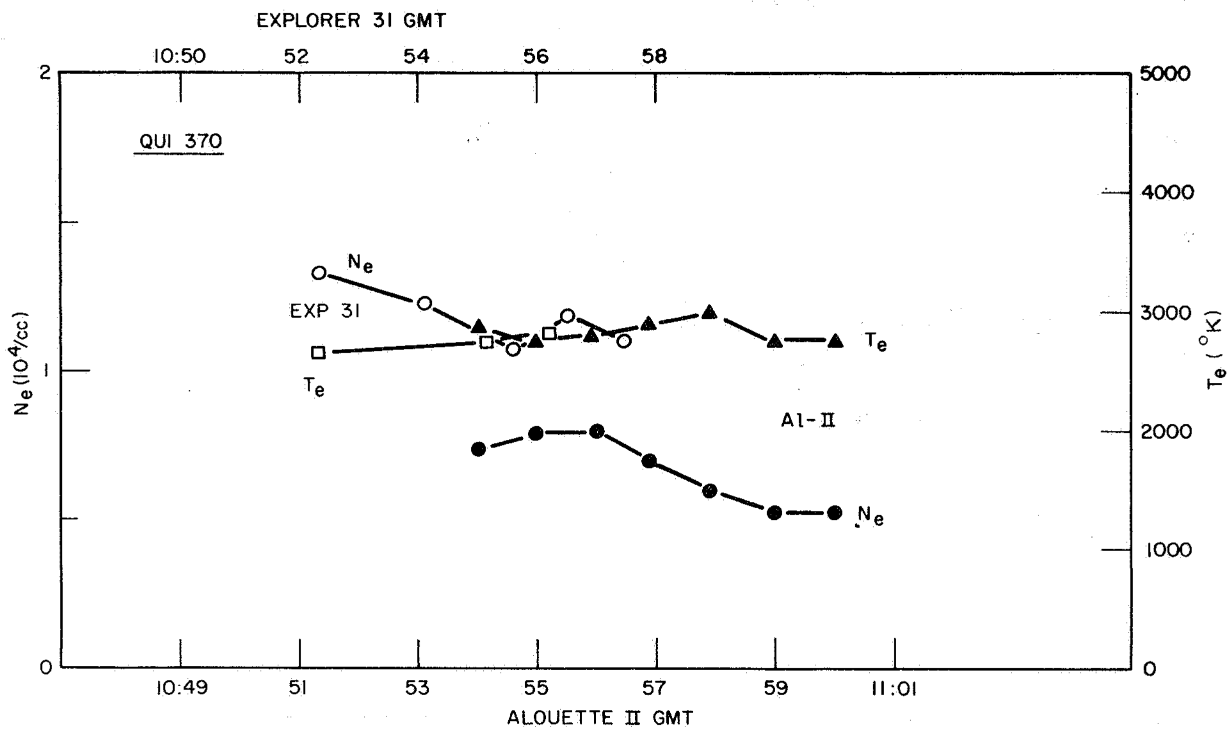

Figure 2—Comparison of Alouette II and Explorer 31 Probe Measurements on a Northbound Equatorial Pass on December 30, 1965, at 1600 Kilometers and a Local Time of 0530

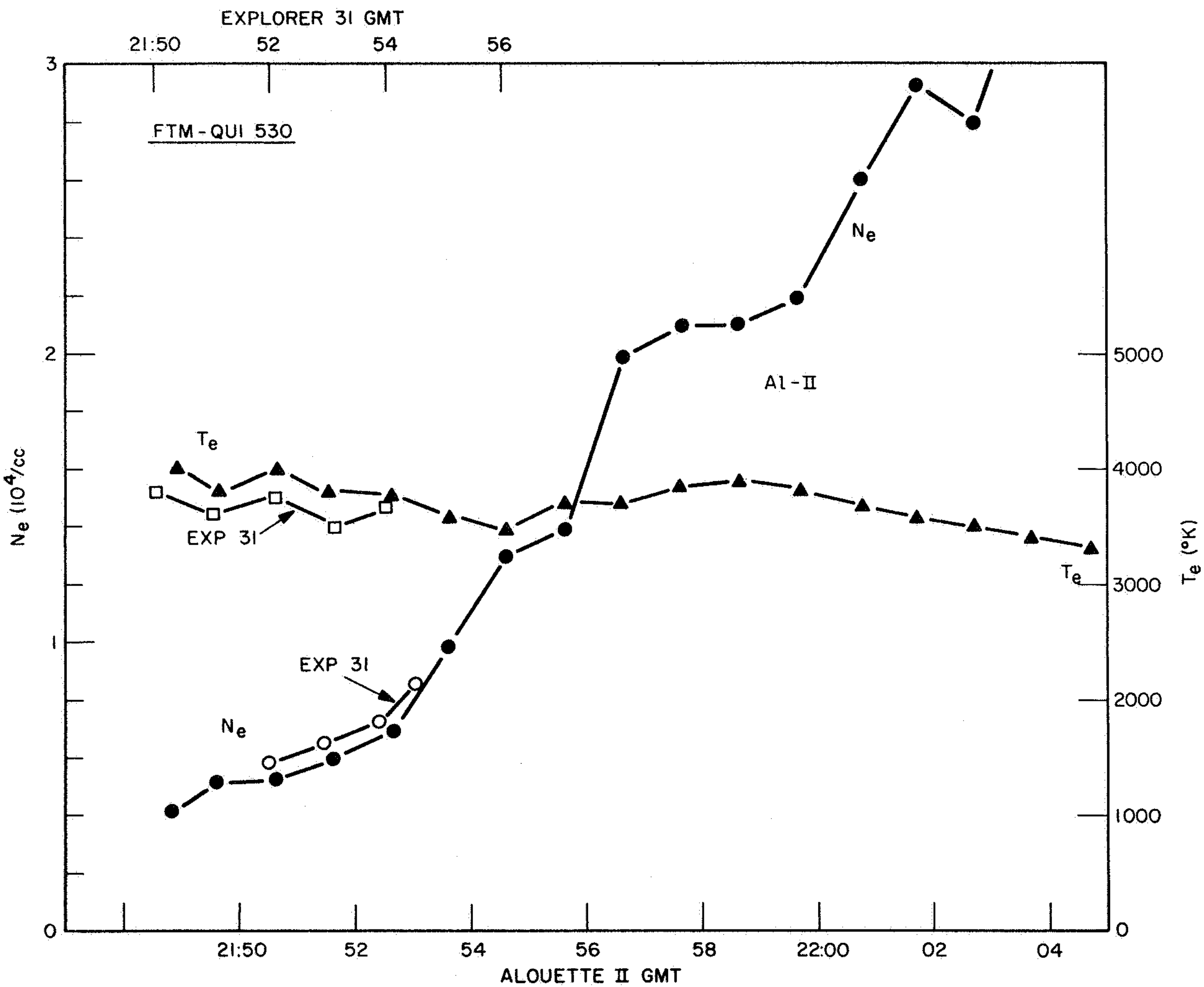

Figure 3—Comparison of Alouette II and Explorer 31 Probe Measurements on a Southbound Pass Approaching the Equator on January 12, 1966 at 1600 Kilometers and a Local Time of 1530 Hours

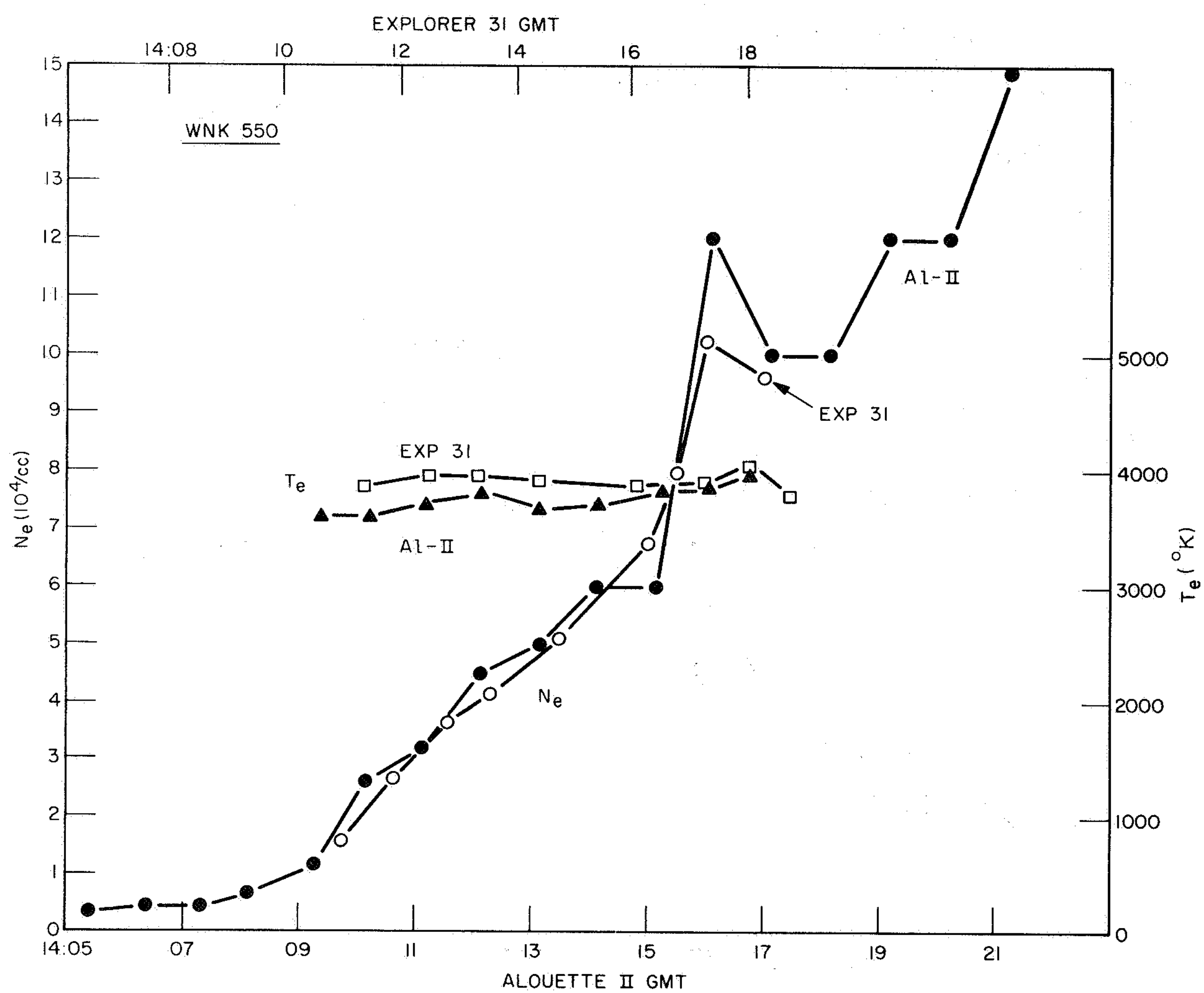

Figure 4—Comparison of Alouette II and Explorer 31 Probe Measurements on a Southbound Midlatitude Pass on January 14, 1966 at 2000 Kilometers and a Local Time of About 1500 Hours

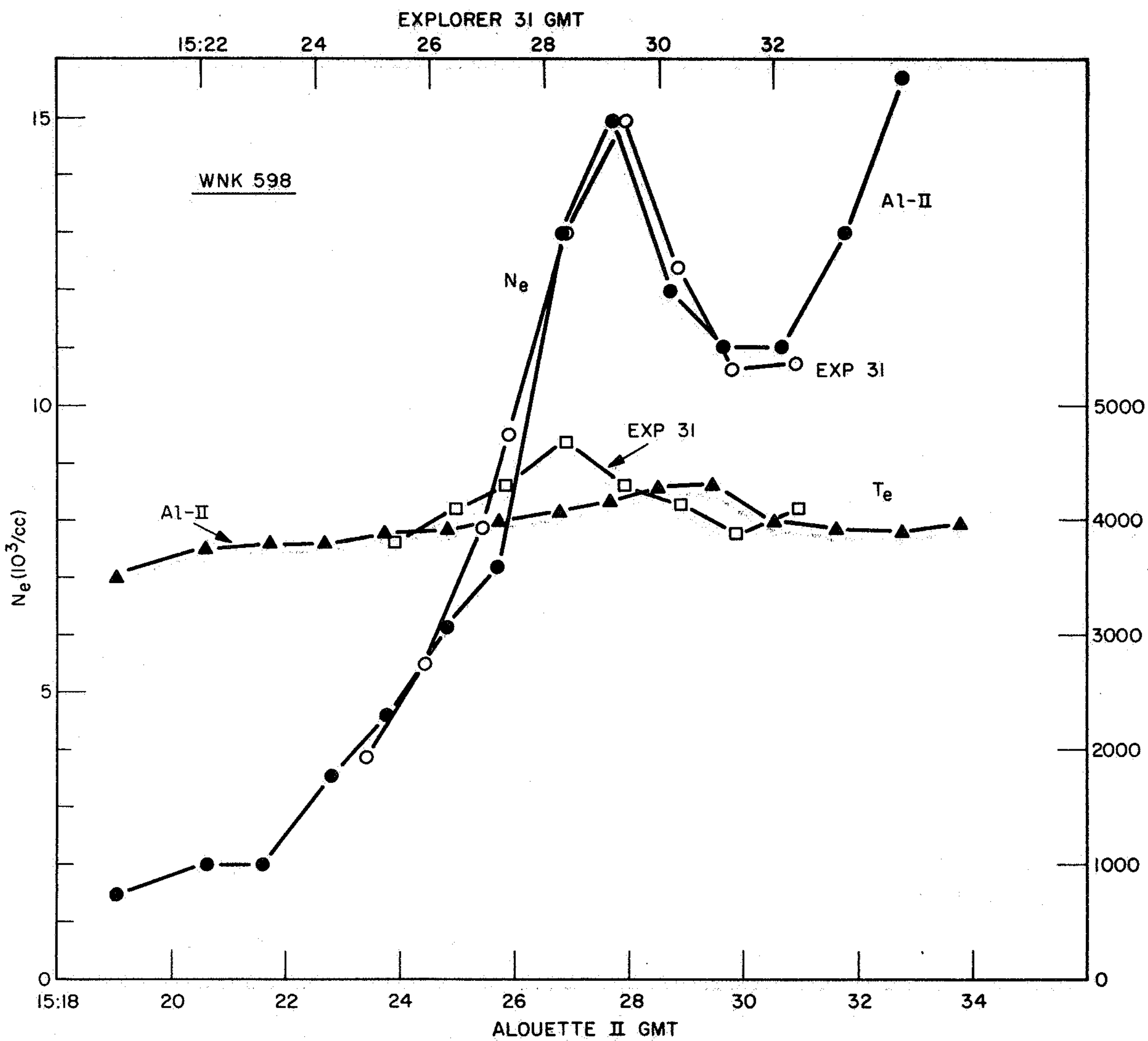

Figure 5–Comparison of Alouette II and Explorer 31 Probe Measurements on a Southbound Middle Latitude Pass on January 18, 1966 at about 1700 Kilometers and a Local Time of 1430 Hours

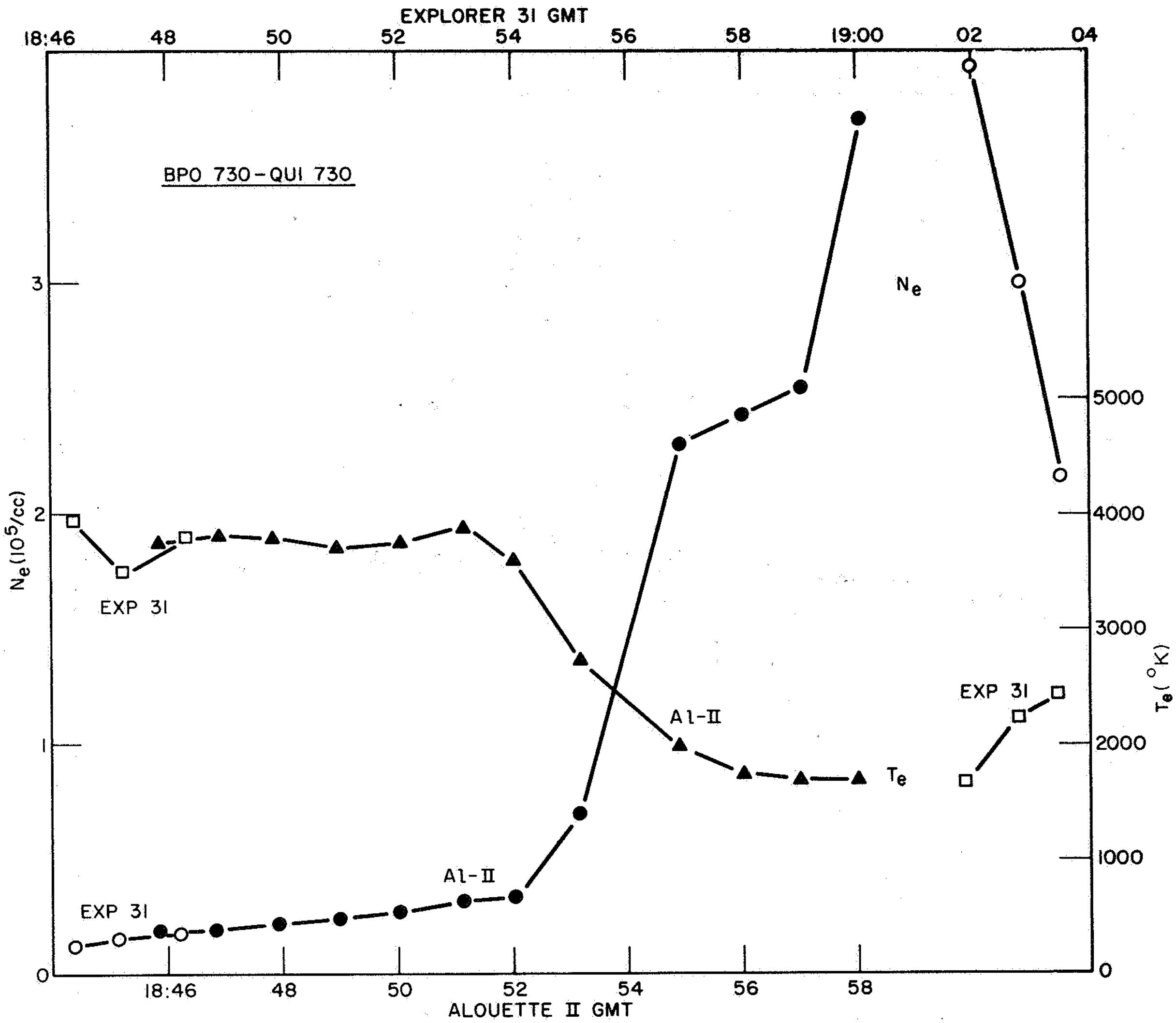

Figure 6—Comparison of Alouette II and Explorer 31 Probe Measurements on a Series of Southbound Passes on January 29, 1966. The Altitude Varies From 1430 Kilometers at the Left to 517 Kilometers at the Right and the Latitude Ranged From 48 °N to 35° south. The Local Time was Approximately 1345 Hours.

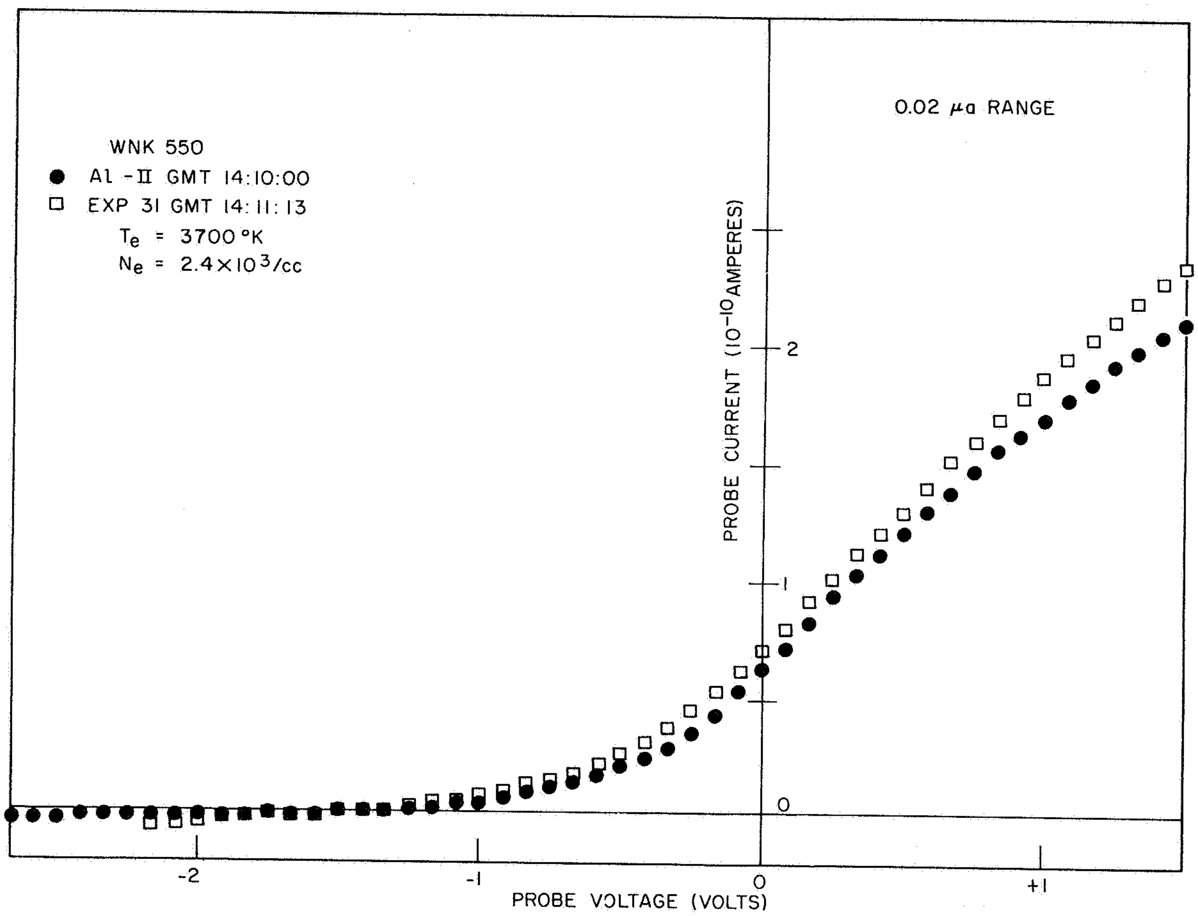

Figure 7—Comparison of Alouette II and Explorer 31 Volt-Ampere Characteristics at Beginning of WNK 550 Pass (Figure 4) Where N_e was Low. The 0.02μa Detector was Employed.

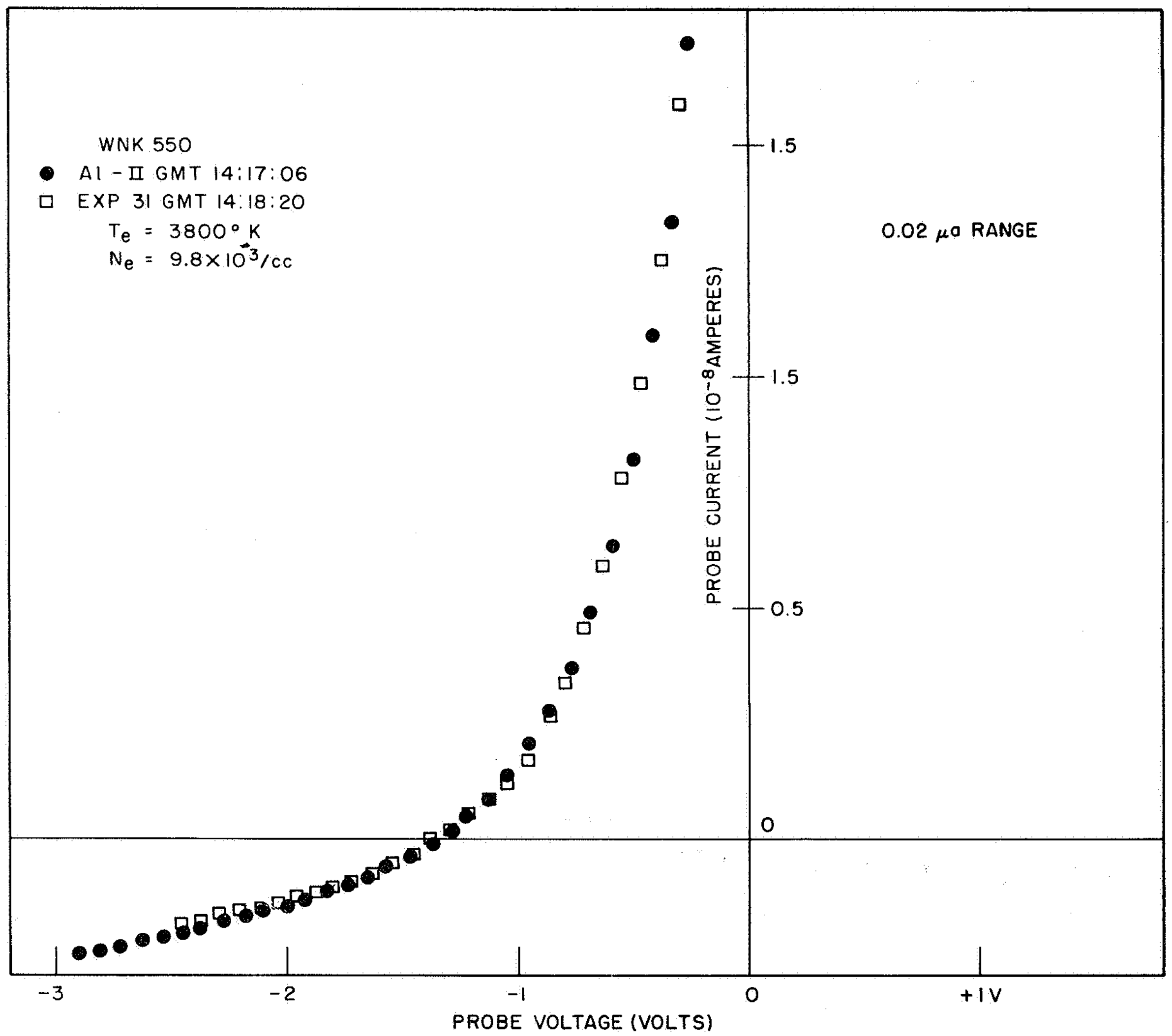

Figure 8–Comparison of Alouette II and Explorer 31 Volt-Ampere Characteristics at the End of WNK 550 Where N_e was About 1×10^4/cc. The 0.02μa Detector was Employed for Analysis of T_e.

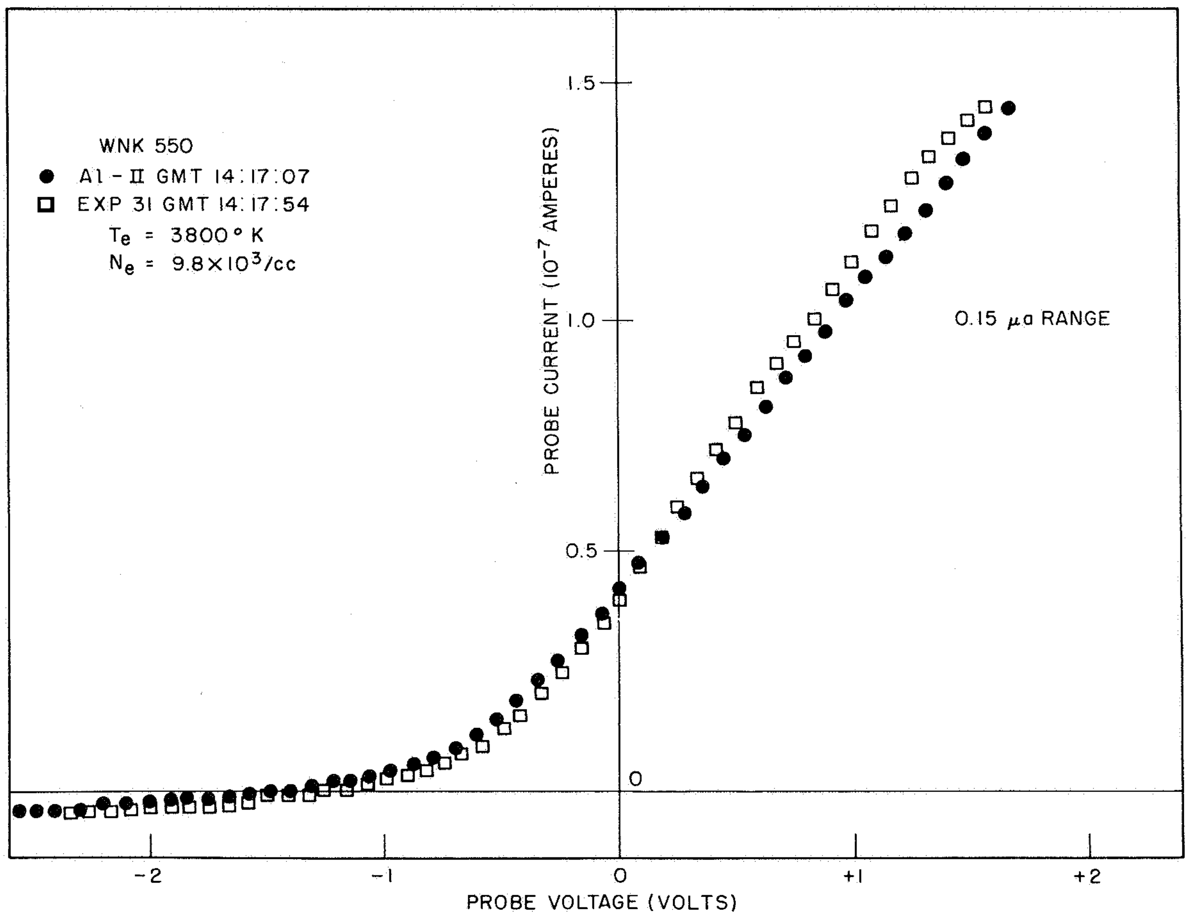

Figure 9—Comparison of Alouette II and Explorer 31 Volt-Ampere Characteristics at the End of WNK 550 on the 0.15μa Detector, Which is Employed for Analysis for N_e at This Concentration

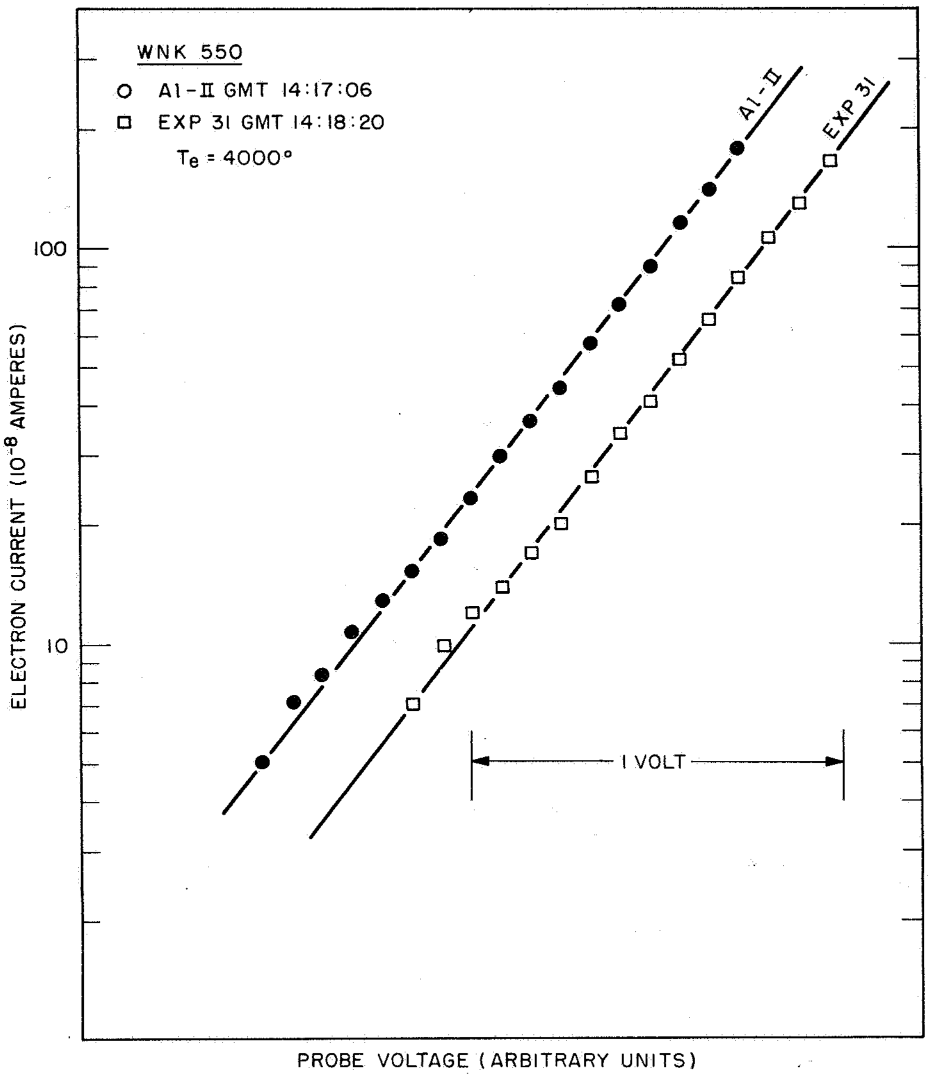

Figure 10–Log Plot of the Electron Currents in Figure 8 Demonstrates the Method of Temperature Analysis and the Comparability of the Data From the two Satellites.